Final Report of AFSR-AOARD Project
AOARD-09-4029

"Study of Equatorial Ionospheric Irregularities with ROCSAT-1/IPEI Data for Assessment of Impacts on Communication/Navigation System (V)"

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November 1, 2009

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
29 DEC 2009	**FInal**	**24-01-2009 to 31-12-2009**

4. TITLE AND SUBTITLE
Study of Equatorial Ionospheric Irregularities with ROCSAT- 1/IPEI Data for Assessment of Impacts on

5a. CONTRACT NUMBER
FA23860914029

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Central University,Institute of Space Science,Chung-Li 320,Taiwan,TW,320

8. PERFORMING ORGANIZATION REPORT NUMBER
N/A

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AOARD, UNIT 45002, APO, AP, 96337-5002

10. SPONSOR/MONITOR’S ACRONYM(S)
AOARD

11. SPONSOR/MONITOR’S REPORT NUMBER(S)
AOARD-094029

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Three tasks completed in this study are presented. (1) The climatologic model of scintillation index S4 map using the ROCSAT data during the moderate to high solar activity period is completed using the ROCSAT 32 Hz density fluctuation data collected at the 600 km altitude. The results are divided into two maps, one for strong scintillation (S4>=0.3) and the other, weak scintillation (S4<0.3). (2) Study of coincident scintillation events between NCU-SCINDA data, COSMIC observations, and C/NOFS observations. Since 2008-2009 are in the solar minimum period, not many scintillation observations were noted. In September 2009, SCINDA hardware and data acquiring software are malfunctioning so that no scientific data has been collected. Ron Catton, AFRL has been contacted to discuss how to remedy the situation. (3) Study of the outer-scale length of turbulence. Initially, the study started with a set of coincident observations made with the ROCSAT data and Ascension Island beacon experiment. The initial results are very encouraging and the study is continuing.

15. SUBJECT TERMS
Atmospheric Chemistry, Atmospheric Science, Ionospheric Irregularities

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**13**	

Summary of Final Report

Completed and Delivered Items:

(1) Completion of Climatologic Model of Scintillation Index S4 Map (Results will be presented in 2010 PIERS Meeting in Xi'an)

The climatologic model of scintillation index S4 map using the ROCSAT data during the moderate to high solar activity period is completed, and will be presented in the 2010 PIERS (Progress in Electromagnetics Research Symposium) meeting to be held in Xi'an, March 22-26, 2010. The model adopts the work of Wernik et al. (Radio Science, 2007), using the ROCSAT 32 Hz density fluctuation data collected at the 600 km altitude then scaled to have the whole the density profile with the IRI model to obtain the global seasonal scintillation index S4. The results is divided into two maps, one for strong scintillation (S4>=0.3) and the other, weak scintillation (S4<0.3).

The results that will be presented in the 2010 PIRES meeting are attached herewith as the Attachment I. Since the ionospheric scintillation is caused by the density irregularities, basically the scintillation map should have the similar seasonal/longitudinal (s/l) distributions of the density irregularity occurrences that have been published before [Su et al., JGR 2005]. However, we notice that only the s/l distributions of weak scintillations (S4<0.3) follow the same s/l distributions of density irregularities. For the s/l distributions of strong scintillations (S4>=0.3), the high occurrence region appears near the equatorial ionization anomaly (EIA) region at the magnetic (dip) latitude around ± 15º~20°. This is because the strength of scintillation is proportional to the amplitude of density fluctuation so that when the background density level is high, the fluctuation amplitude will also be high. As the post-sunset background density still maintains the high density level around the EIA latitudes, it will cause a stronger scintillation.

(2) Study of coincident scintillation events between NCU-SCINDA data, COSMIC observations, and C/NOFS observations.

Since 2008-2009 are in the solar minimum period, not many scintillation observations were noted. With only a few good data collected and analyzed, we found no significant results that are worth reporting. As for the COSMIC data, the data quality of scintillation observation is in doubt so that no comparison with SCINDA observation is made.

Recently, around September 2009, SCINDA hardware and data acquiring

software are ailing so that no scientific data has been collected since then. Communication with new AFRL personnel, Ron Caton has been established to discuss how to amend the situation.

(3) Study of the outer-scale length of turbulence.

Initially, the study started with a set of coincident observations made with the ROCSAT data and Ascension Island beacon experiment. Unfortunately, no significant result was found. Thus the ROCSAT data alone is used to study the outer-scale length of turbulence with the aid of the results of Rino (Radio Science, 1979, 1980) and Wernik et al (Radio Science, 2007). We use the 8-s ROCSAT density irregularity data to locate the bending location in low frequency part of the irregularity spectrum to find the outer-scale length of turbulence. The initial results are very encouraging as seen the Attachment II. Hope that in the next continuing project, we will complete the study.

AFRL-AOAOR Proposal (2010)

"Study of Equatorial Ionospheric Irregularities with ROCSAT-1/IPEI Data for Assessment of Impacts on Communication/Navigation System (VI)"

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December 1, 2009

I. Introduction

ROCSAT's 32 Hz density dataset is collected from March 1999 to June 2004 during the moderate to high solar activity period. This is still the best dataset to study the low-latitude ionospheric scintillations during the high solar activity periods. The global seasonal variations of density irregularity occurrences observed by ROCSAT have been published in the literature [Su et al., 2006, 2007, 2008, 2009]. Since the radiowave scintillation is caused by the density irregularity structure, how the ROCSAT observed global seasonal density irregularity occurrence distribution will truly reflect the global seasonal occurrence pattern of radiowave scintillation needs to be studied. We, thus, initiated such a study in past two years and have completed the global seasonal scintillation occurrence pattern during the last project period.

It is further noted that the 32 Hz data can also be used to study the outer-scale of turbulence with aids of Rino's and Wernik's published results. An initial attempt of such study was carried out in the last project and we found the result very promising. Thus, we propose to continue such a study.

Finally, to study the density irregularity occurrence morphology is to understand the irregularity occurrence property so as to devise a method of predicting its occurrence. This will assist us in predicting the scintillation occurrence as well. We have in 2005-2006 devised a method of predicting the irregularity occurrence based on its occurrence physics. It is an empirical model, and the result is promising. However, it is noted that although the probability of prediction (to predict an occurrence of density irregularity or to predict no such occurrence) is high, around 80% success rate, the false alarm rate is also high. Therefore, in this proposal, we plan to improve the predicting methodology since we now have a better understanding of the irregularity occurrence morphology after past several years' study of such irregularity occurrence morphology.

II. Outer-scale length of turbulence

Using Rino's result of weak scattering formula for the thin phase-screen model [1979], Wernik et al. [2007] devised a formula to find out the outer-scale length of turbulence in the power spectrum of ionospheric density fluctuation,

$$P_s(f) = \frac{C_s \Gamma(\frac{p}{2})}{4\pi^2 \Gamma(\frac{p}{2}+1)} \bullet \frac{1}{V_p [q_0^2 + (\frac{2\pi f}{V_p})^2]^{p/2}}$$

with $C_s = 8\pi^{3/2} < \Delta N_e^2 > q_0^{p-1} \bullet \dfrac{\Gamma(\frac{p}{2}+1)}{\Gamma(\frac{p}{2}-\frac{1}{2})}$

Here p : one-dimensional spectral index

q_0 : outer-scale wave number

V_p : spacecraft velocity

C_s : turbulence strength parameter

$< \Delta N_e^2 >$: variance of electron density

Since the density variance $< \Delta N_e^2 >$ and the spectral index can be thought as fixed values obtained from ROCSAT data. The outer-scale length changes as the location of spectral shape changes in the power spectrum at the lower frequency region as seen in Figure 1. On the other hand, if we treat the spectral index (slope), density variance, and the outer-scale as variables, we can use a least-squares fit to the density spectrum to obtain an outer-scale length of turbulence as shown in Figure 2. The cause of generating the outer-scale length in the ionsopheric density irregularity structure is related to the seeding wavelength in the generalized gravitational Raleigh-Taylor instability process in the bottomside ionosphere. Thus understanding the variation of the outer-scale lengths in a global seasonal distribution could shed lights to the causes of the seeds for the Raleigh-Taylor instability which is an important scientific research topic.

In this proposal we shall examine the best approach to obtain a consistent and realistic outer-scale of turbulence in the density irregularity structures observed by ROCSAT-1 at the 600 km altitude during the moderate to high solar activity years of 1999 to 2004.

III. Predicting the Occurrence of Density Irregularity Structure Ahead of the Satellite Trajectory.

The day-to-day variability of the occurrence of ionospheric density irregularities has been noticed since the ground observations of spread-F events in the past decades. It is has been, so far, an important scientific problem to

understand the cause of irregularity occurrences so as to predict the occurrences. We have been studied this problem since the beginning of studying the density irregularity events collected by ROCSAT. We have devised an automatic search program to observe the unusual density variation ahead of the occurrence of an irregularity event along the ROCSAT's orbit. Figure 3 shows the method of such search. After removing the density background value, we check the residual density level to see if four (4) successive increases of density level existed along a ROCSAT trajectory. If they do, then an irregularity occurrence is predicted. If not, then there should be not such event. The result, as studied in 2005, is shown in Figure 4 for one day, and in Figure 5 for the predicting result from 1999 to 2004. Although Figure 4 indicates such a scheme of prediction works in this example, the false alarm is also high as noted in the final result of Figure 5. Since then, we have carried out many in-depth studies of the occurrence property and morphology of density irregularities [Su et al., 2006, 2007, 2008, 2009], and now we have a better understanding of the major causes of the irregularity occurrences. They are the geographic location of the dip equator to affect the ionospheric seasonal density variation, the magnetic declination angle to affect the longitudinal gradient of the ionospheric conductivity across the sunset terminator, and the strength of the geomagnetic field at the dip equator to drive the over-all electrodynamics. Therefore, in this proposal, we will devise a system of using different occurrence criteria for different geographic/geomagnetic/seasonal locations of detection. We think the new study should improve our predicting capability of irregularity occurrences. If the result is good, we would like to extend such an approach to the C/NOFS observations that are made at slightly different altitudes.

IV. Deliverables

1. 6/2010

   Study of the outer-scale length of turbulence in the density irregularity structures observed by ROCSAT. Global/seasonal distributions of the outer-scale length of turbulence in the density irregularity structures will be completed.

2. 11/2010

   The improved prediction result of density irregularity occurrences will be completed. This method will then be applied to the data collected by C/NOFS.

V. Qualifications of Principal Investigator and Co-Principal Investigator

The Principal Investigator (PI) is Professor C. H. Liu, Vice President of Academia Sinica, Taipei, Taiwan and Adjunct Professor of National Central University, who is a Professor Emeritus of the University of Illinois, U. S. A. Professor Liu is a Fellow of IEEE, Academician of Academia Sinica, Republic of China and Academician of Third World Academy of Sciences (TWAS). He has published 138 Journal papers and is the author (with late K.C. Yeh) of a book, Theory of Ionospheric Waves.

The Co-Principal Investigator (CoPI) is Professor S.-Y. Su, Professor of National Central University, who is the Principal Investigator of the Ionospheric and Plasma Electrodynamics Instrument (IPEI) onboard the ROCSAT-1 (1999-2004) satellite orbiting at 600 km circular orbit with a 35° inclination. He has published 48 Journal papers (as of November 2009) since 1999 with results of ROCSAT-1/IPEI observations.

VI. Proposed AFRL TD PM: Dr. Keith Groves, Space Weather Center of Excellence, AFRL, Hanscom AFB, MA, USA.

VII. AOARD PM: Dr. Pon R. Ponnappan Tokyo, Japan.

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Wernik, A. W., L. Alfonsi, and M. Materassi (2007), Scintillation modeling using in situ data, Radio Sci, 42, RS1002, doi:10.1029/2006RS003512.

Equation variation with Outer scale (Constant: spectral Index and electron variance; Variable: outer scale)

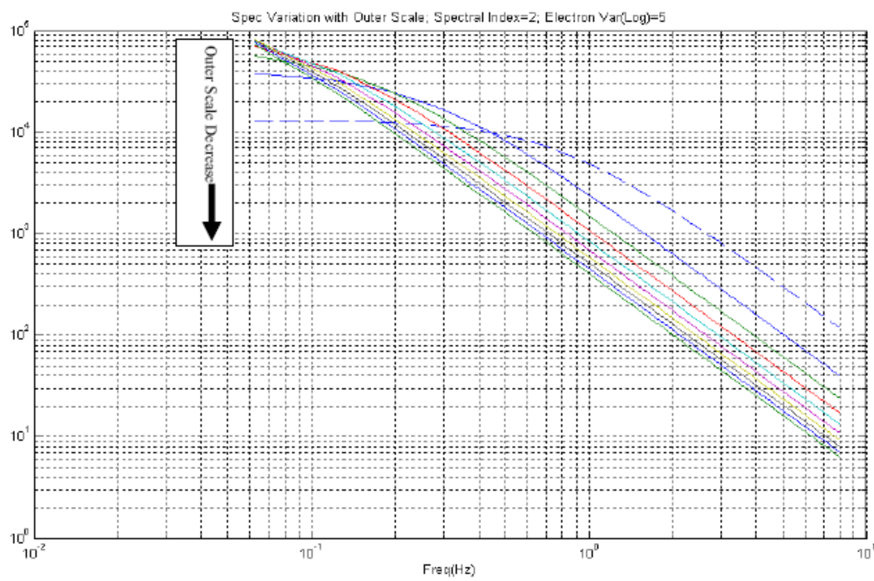

Fig.1. Changes of the outer-scale of turbulence due to different locations in the bending place in the spectral lines with a fixed spectral index.

LSQ Log Fitting (Variable: spectral index 、 outer scale & electron variance(G))

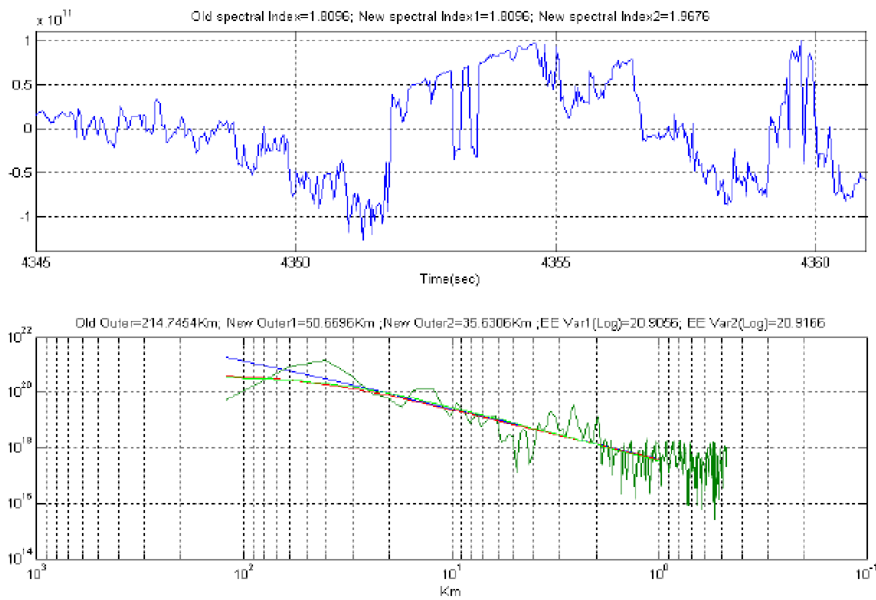

Fig. 2. Example of a test case using the least-squares fit to the power spectrum in the ROCSAT observed density irregularity structure.

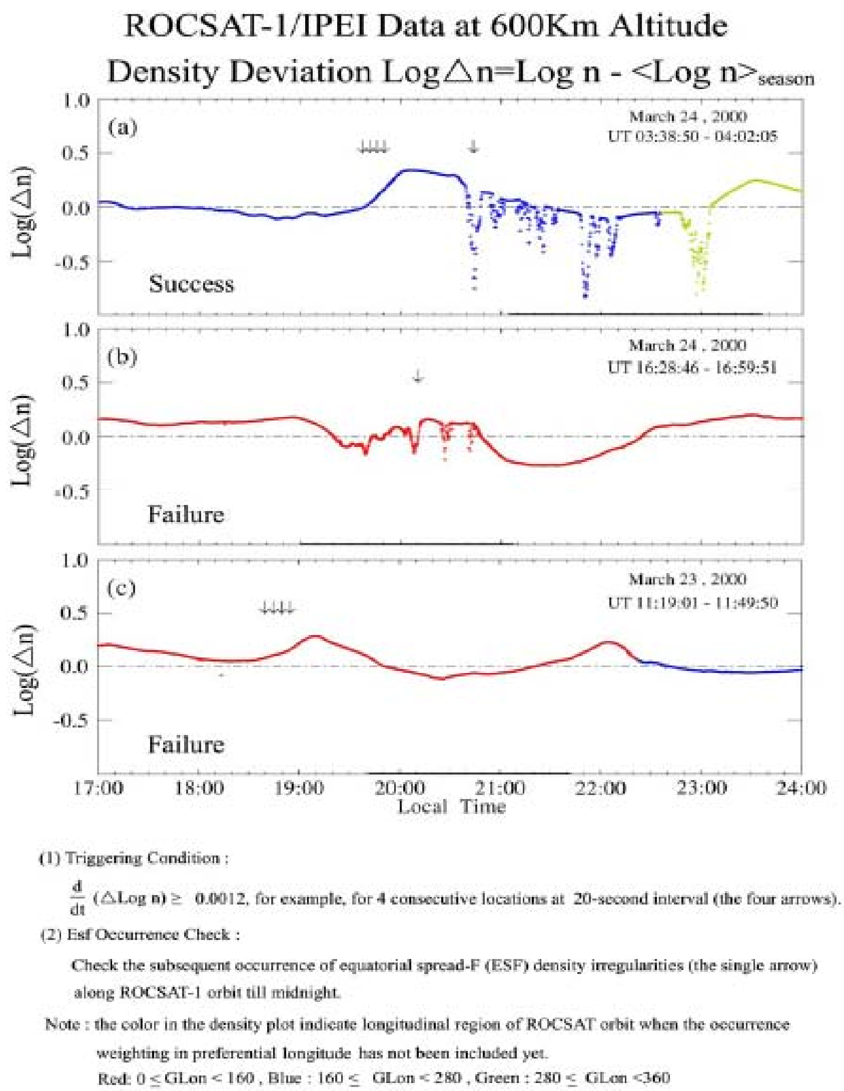

Fig. 3. Method of predicting an irregularity occurrence from density variation along the ROCSAT trajectory. The arrow indicates that the density increase fits the criterion.

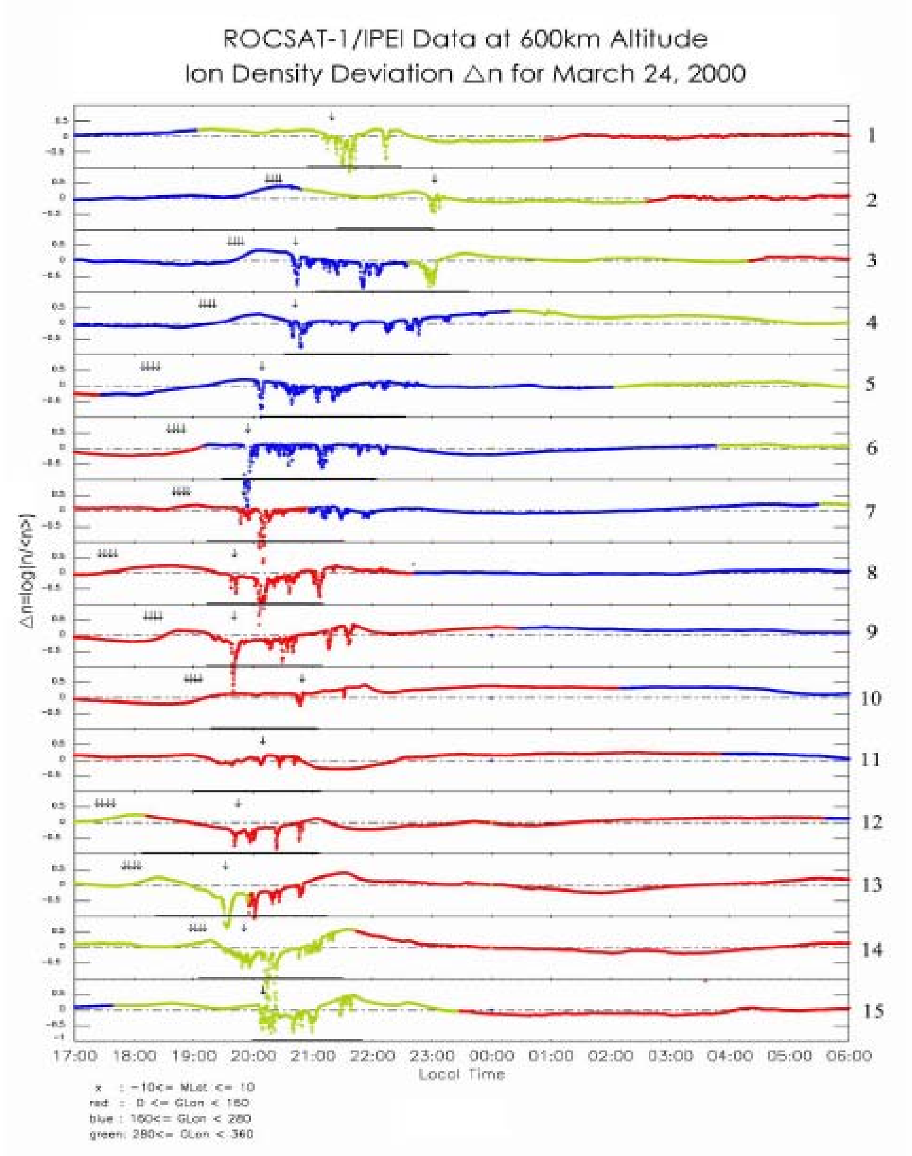

Fig. 4. Example of predicting irregularity occurrences in 15 orbits on March 24, 2000.

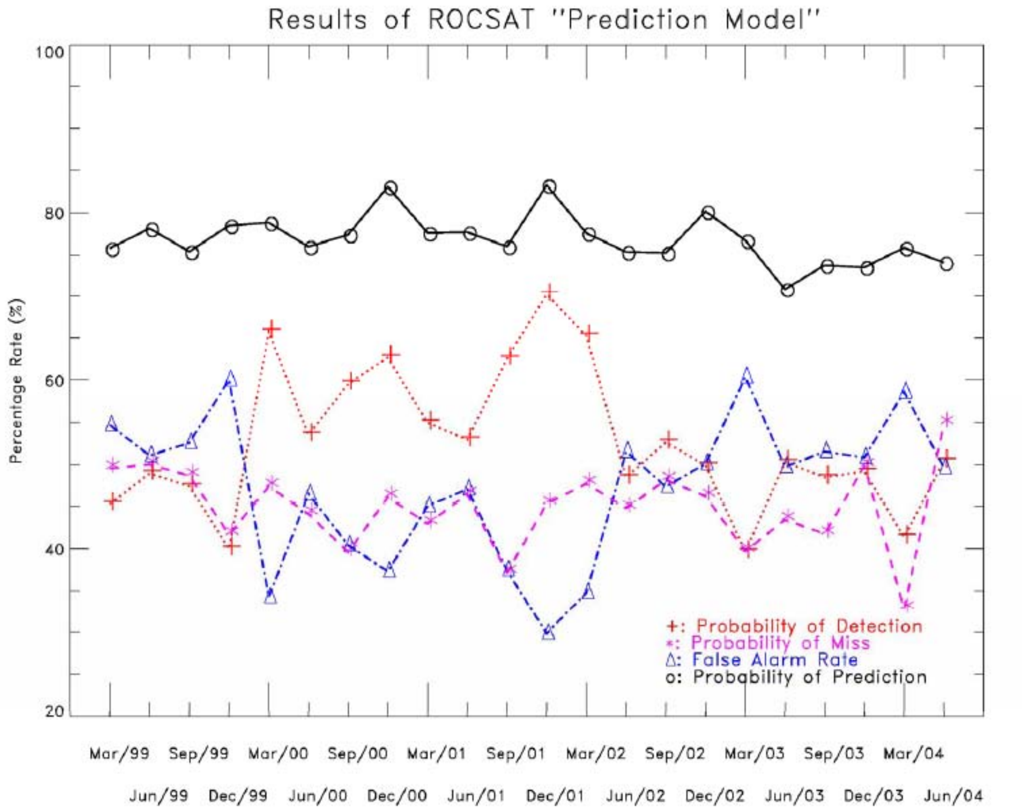

Fig. 5. Results of predicting an irregularity occurrence from 1999 to 2004.